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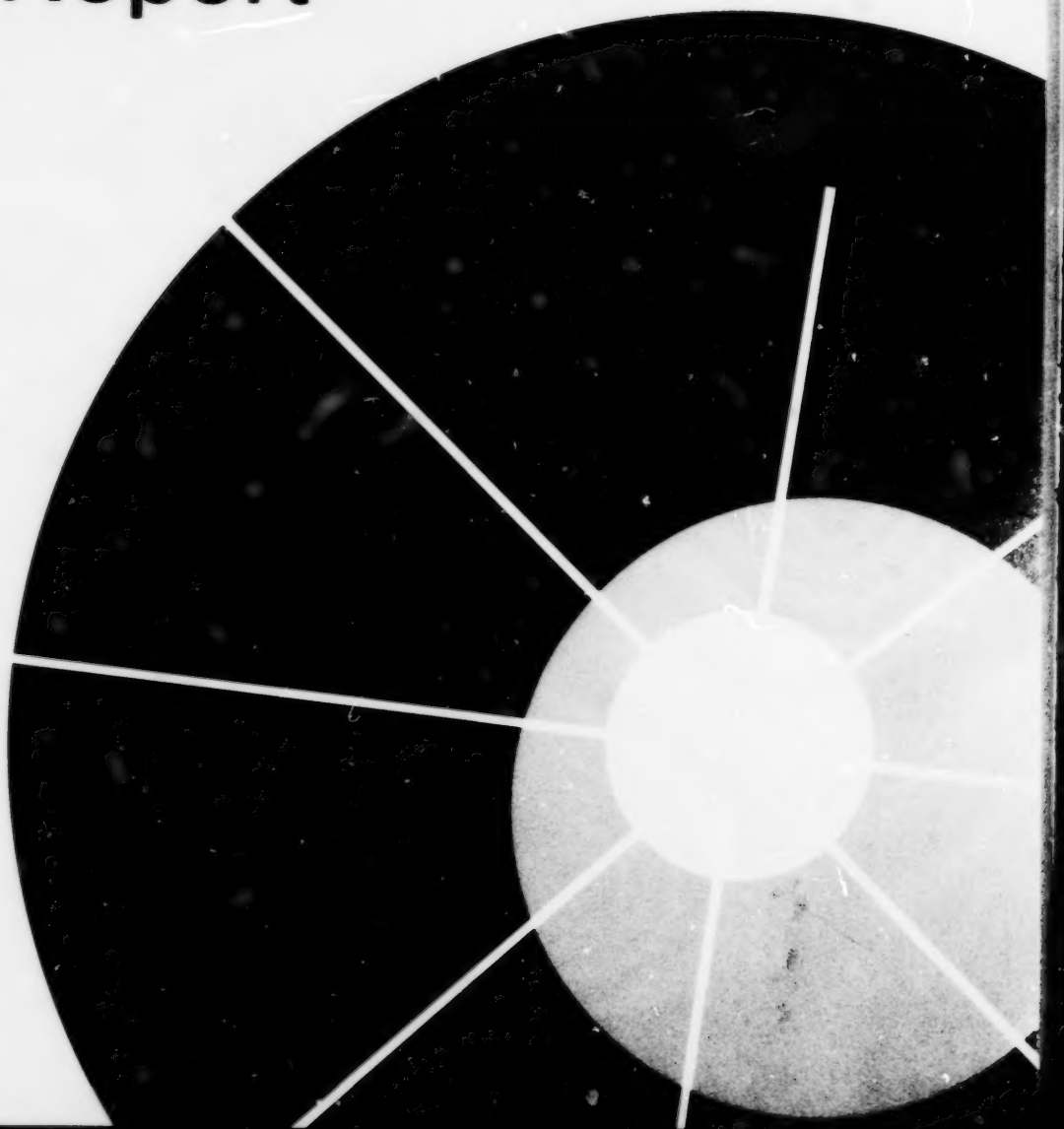
Canada - Saskatchewan Renewables — Conservation Demonstration Program

Final Report



CANADA-SASKATCHEWAN CONSERVATION AND RENEWABLE ENERGY DEMONSTRATION AGREEMENT

On March 18, 1980, the governments of Canada and Saskatchewan entered into a Conservation and Renewable Energy Demonstration Agreement. The Agreement, which terminates March 31, 1984, funds the development and demonstration of a wide range of conservation and renewable energy technologies. The program is funded on an equal cost-shared basis by Canada and Saskatchewan, and is administered by Saskatchewan.

The objectives of CREDA are:

— To develop and demonstrate promising new technologies which exploit renewable energy resources, conserve energy, or make its use more efficient;

— To create employment in new or existing industries;

— To develop broad public awareness of the potential of renewable energy and energy conservation technologies.

This report outlines the results of a project funded by the Government of Saskatchewan as represented by Saskatchewan Energy and Mines, and the Government of Canada as represented by Energy, Mines and Resources Canada, under the terms of the Renewables-Conservation Demonstration Program, and contracted with the party identified herein.

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SASK. 36

Earth-Sheltered Residence

Final Technical Report
on a Renewables-Conservation Demonstration Program Project

Conducted By

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And Supported By

Saskatchewan Energy and Mines
and
Energy Mines and Resources Canada

Project Leader: Wade Keeler

Miscellaneous
Report FP-34

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This report consists of a detailed assessment of the design and construction of an earth-sheltered house at Keeler, Saskatchewan. A representative from Saskatchewan Research Council visited the house on March 23 and spent several hours on inspection and discussion with the owner.

This work was conducted at the request of Saskatchewan Energy and Mines. This report is submitted in fulfillment of this work.

The energy crisis of 1973 triggered a widespread interest in all forms of energy conservation. One of the most visible signs of this interest was in the residential sector; homeowners, builders and architects began to explore a wide range of residential energy conservation concepts. Eleven years after the energy crisis, in 1984, we can look back and note that some of the concepts have survived, but many have been discredited.

The surviving concepts can be grouped into two categories: firstly there are technically proven concepts with relatively high cost-effectiveness, that can be applied in most situations. Super-insulation and airtight construction are the foremost examples in this group, and these are being adopted on an ever-increasing scale. The second group consists of concepts that are technically proven, but whose cost-effectiveness and application varies according to climate and other localised factors. Such concepts may be highly effective in one set of circumstances, but ineffective in another. Active solar heating systems and earth sheltering fall into this second category.

Underground houses and earth-sheltered houses have proved to be popular concepts in the move towards increased thermal efficiency in houses. Originally, these concepts appear to have been based on the mistaken belief that earth was a good thermal insulator. Even in 1973 there was enough information in the technical and public literature to discredit this assumption. Nevertheless, the concept has persisted and earth sheltered houses are steadily increasing in number, particularly in the United States (1).

With the benefit of ten years of operational experience, the advantages and disadvantages of earth sheltering are becoming more clear. Protection against extreme storms is one of the main advantages, and this explains why these designs are particularly popular in the mid-western United States. Other owners cite the increased security against burglary and the reduced insurance premiums that result from this. Sound insulation is another benefit that has proved attractive to owners of these houses.

On the debit side, these houses may cost considerably more than the conventional house. The incremental cost relates mainly to the building shell, which has to be extra strong to resist the high loading imposed by the surrounding earth. It is claimed that the investment in an extra strong building shell is good policy, since it also ensures a greater lifetime for the house. This may not always be true; in some soil types a 'buried' house may deteriorate more rapidly than one built on the surface. Underground houses and earth-sheltered houses have not been around long enough to allow a proper evaluation of this aspect.

Since most of the surface of these houses is covered by soil, the owner will not be faced with the usual surface maintenance costs associated with conventional houses - ie. re-shingling, re-siding, painting, etc. This is a valid point, but once again it must be noted that these houses have not been around long enough to establish whether or not they require other kinds of maintenance.

The most cost-effective earth sheltering designs are those that make best use of the local terrain: for example, by building into a south-facing hillside. This minimises the costs of excavation and backfill, and it may also solve local soil-drainage problems. If the house is built on flat terrain (as in this project), then extra cost penalties are incurred in berming and providing appropriate drainage.

Let us now look at the technical performance of earth-sheltered houses in more detail.

First let us consider the thermal resistance of soil. There appears to be a general misunderstanding about this, which can be traced to the fact that soil thermal resistances are expressed in terms of a one-foot thickness, whereas the thermal resistance for constructional materials is given for a thickness of one inch. A one-foot thickness of soil may have a thermal resistance anywhere in the range R SI 0.053 to 0.23, depending on the soil type, compaction and moisture content. Given good drainage and fairly low compaction, the soil around a house will probably

have a thermal resistance in the range RO.7 to RO.9 per foot. Thus, one foot of soil has about the same thermal resistance as about a quarter of an inch (6 mm) of glass fibre batt insulation. In a moderately energy-efficient house, with 6" (140 mm) stud walls and R20 batt insulation, it would take a layer of soil 25 ft thick to give the same level of insulation. Therefore, in terms of thermal insulation, soil compares very poorly with standard constructional insulation materials. It has been necessary to make this point to remove any misconceptions that may exist, but at the same time it must be emphasised that the advantages of earth-sheltering do not derive from the insulating effect of the soil.

The main effect of earth sheltering derives from the very large thermal mass of the soil, which tends to smooth out the large seasonal variations in temperature. In a typical climatic year in Saskatchewan, the air temperature may swing from -30°C to +30°C. This temperature variation can be viewed as a temperature wave which moves down into the soil. At the surface of the soil, the temperature of the soil will follow the climatic temperature changes fairly precisely. As we go deeper into the soil, we find that the range of the temperature swing (ie. the amplitude of the temperature wave) reduces progressively with depth. Thus, at a depth of 5 ft(1524 mm), the soil temperature will display a reduced swing, typically from +10°C to 0°C. At a depth of 10 ft (3048 mm) the temperature swing will be even less pronounced, typically from 2°C to 5°C.(2).

This temperature variation in the soil has two main features that bear on the earth-sheltering effect:

- The mean annual temperature of the soil tends to be the same at all depths, and is usually about 3°C above the mean annual climatic temperature. For Saskatchewan conditions the mean annual temperature of the soil is usually close to +3°C.

- The climatic temperature variations do not penetrate the soil instantly; they take a considerable time to affect the soil temperatures at depths of 5 ft or more. Putting this more quantitatively: the temperature wave moves downwards into the soil at a speed of typically 3 to 7 ft per month, depending on soil conditions. As the wave moves downwards, its amplitude decreases, as mentioned earlier.

In practice this means that, at a depth of 10 ft (3048 mm), the coldest soil temperatures will occur anywhere from 6 weeks to 3 months after the coldest climatic temperatures. In an earth-sheltered house, the surrounding soil will therefore reach its lowest average temperature sometime around the end of March. The maximum rate of heat loss to the surrounding soil will therefore occur around this time - and this effect tends to be compensated by the increased passive solar gains around early spring. In effect, the soil delays the period of maximum below-grade heat loss to a time when it can be compensated by solar gains

Consider the heat loss through a concrete wall. If the outside of the wall is fully exposed to air temperature changes, then, over the heating season, the outside wall temperature will have an average level of about -15°C. The inside wall temperature will have an average value of about +16°C. The temperature drop through the wall is therefore 31°C. Now consider what happens if this wall is below grade, and extends from grade level to a depth of 8 ft (2438 mm) below grade. The soil temperature in contact with the wall, averaged over the wall height and over the heating season, will be about 2°C. The wall will operate at a higher temperature and its interior surface will also be slightly warmer - probably around 18°C. The temperature drop through the wall will therefore be around 16°C. The soil therefore reduces the temperature drop through the wall from 31°C to 16°C - approximately a factor of two. This reduces the heat loss through the wall by the same factor of two. This is an over-simplified model, but it will suffice for the purposes of this report. In reality, the house creates a warm temperature zone in the surrounding soil, which further reduces the heat loss.

The moderating effect of the soil also extends into the summer season. A large proportion of the house envelope is surrounded by soil at a relatively low temperature - in the range of 2°C to 12°C. This tends to cool the house during summer, and may eliminate the need for air conditioning.

Houses lose a considerable proportion of their heat through air infiltration, and it is sometimes claimed that the surrounding soil restricts this infiltration. In fact, soil offers very little resistance to air leakage and will make only a marginal improvement in this respect. However, on earth-sheltered houses, it is essential to construct a building shell that has sufficient strength and integrity to withstand the extra soil loading. Such shells serve as a very effective air leakage seal - provided that they are constructed correctly and maintain their integrity over the lifetime of the house.

The earth-sheltered house is located on a farm near the town of Keeler in Saskatchewan, approximately 42 km north-west of Moose Jaw. The owner was attracted to the earth-shelter concept by articles in the magazine "Popular Science", and followed this up by inspecting an earth-sheltered farmhouse near the town of Lajord, Saskatchewan.

The owner engaged the company of Grolle Architect and Engineer Ltd., of Regina, to prepare plans of the structural and concrete work. The interior layout and design was conducted by Ingold Design Ltd. of Moose Jaw.

Construction was started in the summer of 1981, with the owner acting as his own general contractor and hiring various sub-contractors to do different parts of the work. Domco Construction Ltd. of Moose Jaw was engaged to do the concrete pouring, and this work was started on June 1, 1981.

On June 5, 1981, the owner made a submission to Saskatchewan Energy and Mines*to have the house monitored and demonstrated under funding from the Federal-Provincial Conservation and Renewable Energy Demonstration Agreement (CREDA). The submission was reviewed and approved for funding.

At that time, the owner expected to be able to move into the house around the spring of 1982, and it was proposed to monitor the house for a period of about 20 months. It was originally intended to have the house monitored by SRC. However, due to constructional delays, the home has not been completed and hence no monitoring has been undertaken.
In March 1984, Saskatchewan Research Council was engaged by SEM to inspect the house, evaluate it and present the findings in a report.

* At that time the Department of Saskatchewan Mineral Resources (SMR).

A member of SRC staff visited the house on March 23 and spent several hours on inspection and discussion with the owner. It was discovered that the construction has proceeded far more slowly than was planned. The south wall (the only exposed wall)had been fully closed in, with all windows and doors in place. Most of the interior framing, including floors and partition walls, was complete, and most of the insulation was in place. The mechanical, electrical and finishing work still remained to be done. On the outside of the house the concrete shell had been insulated with urethane foam and all the earth work was complete (see figure 1).

Figure 1. View of the house from the south

Eight photographs of the house are presented in Appendix I.

During the course of the inspection a number of problems were identified. Some of these were inherent in the design and others had been created by the owner's departure from the original design. The proposed system of air management and combustion air supply would, if pursued, create a number of operational problems and might possibly create hazardous problems in the house. Some time was spent in discussing these matters with the owner, and a number of suggestions were made for improving the designs. However, in some instances, the construction had been taken too far to permit the proper remedial actions to be taken.

Following the inspection, a more detailed study was conducted on the house plans and on the problem areas identified during the inspection. Building codes were studied to determine if there were any infringements. These paper studies revealed a few more problem areas, which will be brought to the attention of the owner.

The general findings from the inspection and the paper study are presented in the remainder of this report.

4.1 General site details

The house is located in a farm yard close to Highway #42 and about 42 km north-west of Moose Jaw. It is protected on the east by a wind-break of mature trees and has an existing farmhouse to the south (see figure 2). The structure is orientated slightly away from due south ; the south wall faces about 10° west of south. This was done deliberately to avoid snow build-up at the main entrance of the house on the south-west corner. The culvert and dugout were installed as part of the general earth work, and will be discussed later.

4.2 General design details

The house consists of a single storey over a crawl-space, and has 3 bedrooms and 1½ bathrooms. The heated living area is 136.8 m² (1472 ft²) and the total area, including garage, is 184 m² (1984 ft²). The dimensions are 32 ft x 62 ft (9753mm x 18897mm). The roof, the crawl space floor and the three earth-sheltered walls consist of poured concrete. The south wall is a combination of concrete support structure and wood-frame. (see figures 3 and 4).

4.3 Site Preparation

Soil was excavated to a depth of about 2.5 ft (762 mm). There is a slight ground slope at the site.

4.4 Concrete forming

The concrete is reinforced with steel bars throughout. Approximately 250 cu. yds. (191 m³) of concrete were used. This was delivered to site, and a concrete pump was used for filling the wall forms.

The walls and crawl space floor were poured at the same time. When these had been allowed to cure the forms were removed and work was started on the roof. Roof forms and re-bar were installed, together with

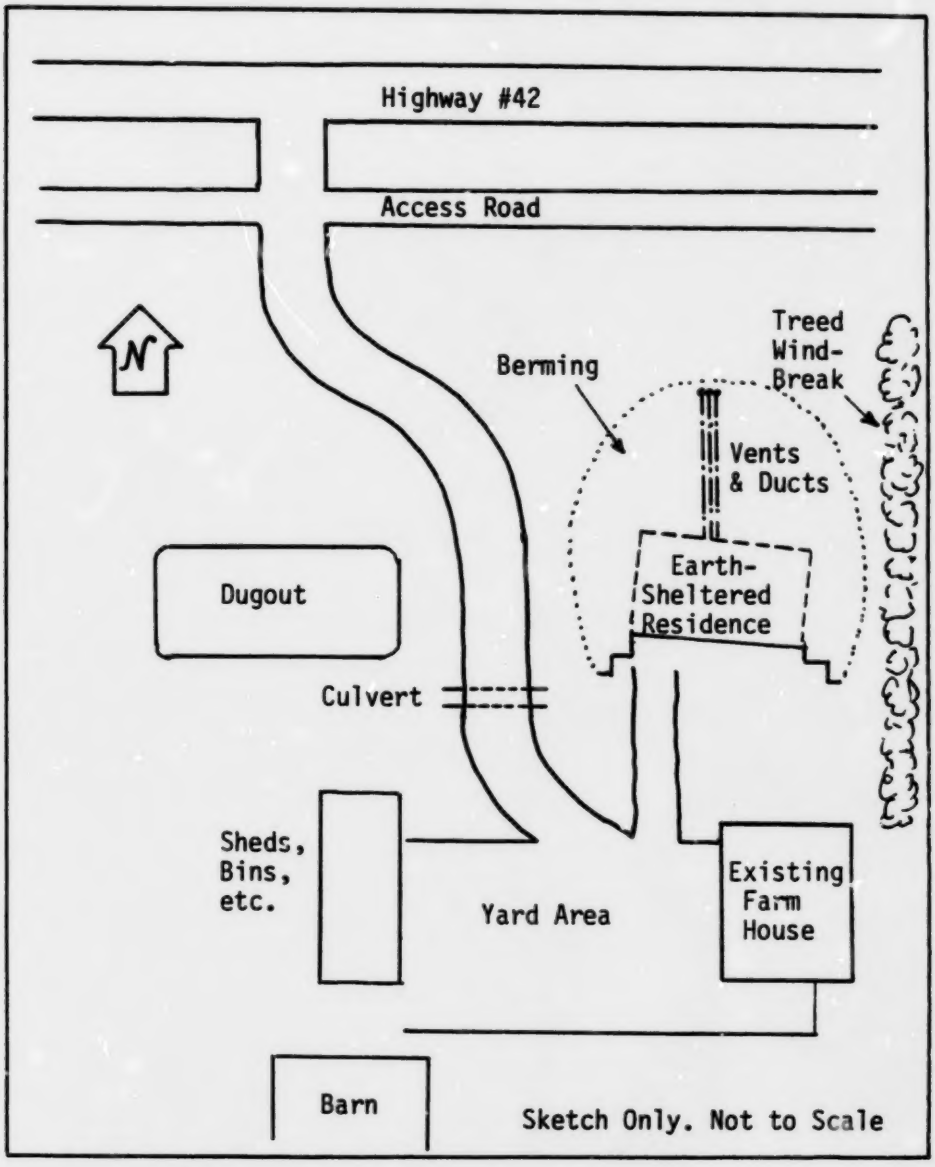


Figure 2. Site Layout

1 MAIN FLOOR PLAN
GARAGE
STORAGE
LIVING
DINING
KITCHEN
BEDROOM #1
BEDROOM #2
BEDROOM #3

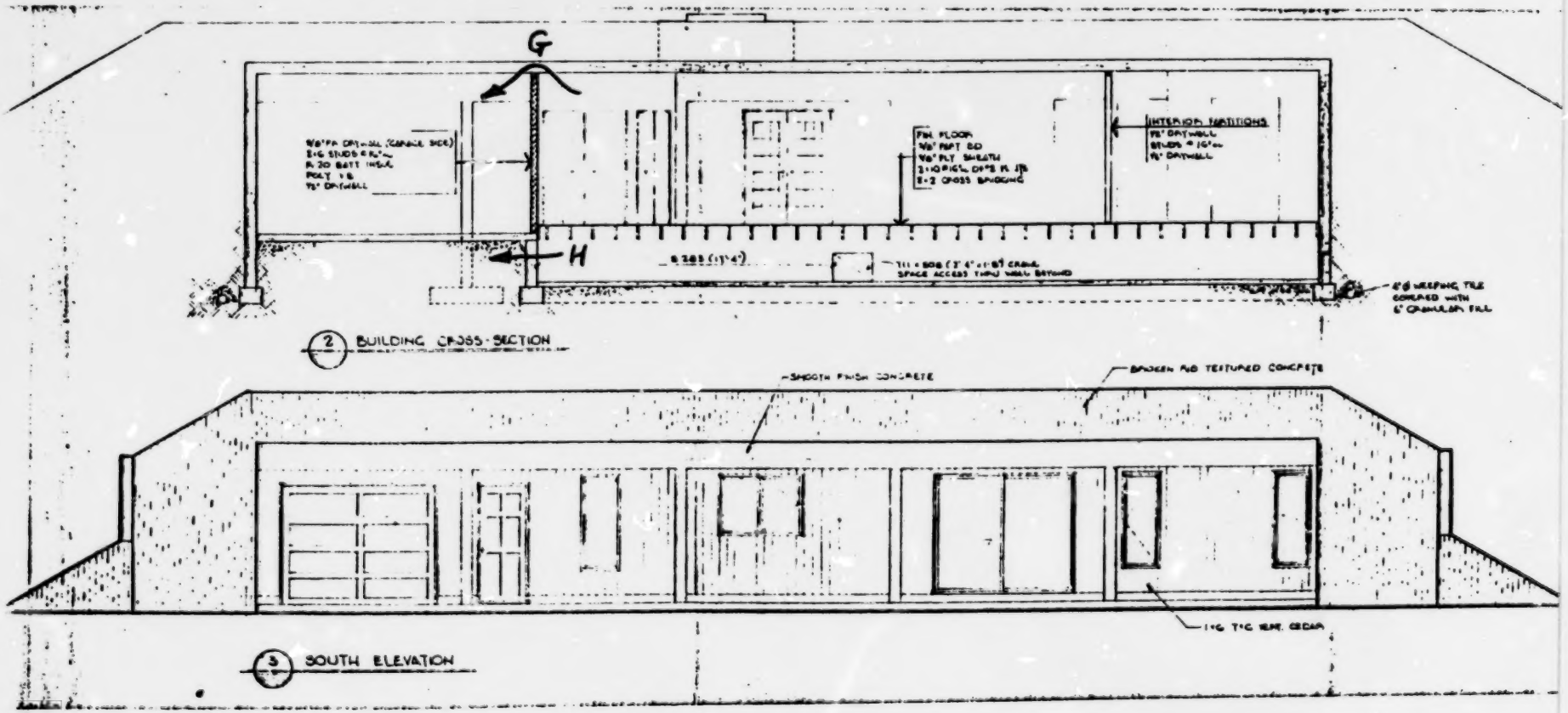


Figure 4. South Elevation and Cross-Section

forms and re-bar for the parapet wall on the south edge of the roof (This parapet wall retains the soil on the roof.). The roof and parapet were poured at the same time.

The concrete wing-walls were installed last, and were poured separately to permit the installation of a thermal break at the corner of the house envelope. At the time of pouring the house walls, sections of re-bar were left protruding from the south ends of the side walls. Rigid insulation was fitted over the re-bar, which still protruded enough to key into the wing-walls. Concrete forms were placed for the wing walls and the concrete was poured to make contact with the rigid insulation (25 mm Dow SM). A crane and concrete bucket were used for this work.

The styrofoam thermal break was not visible at the time of inspection, and the owner was not able to give precise details. The design is assumed to be as shown in figure 5.

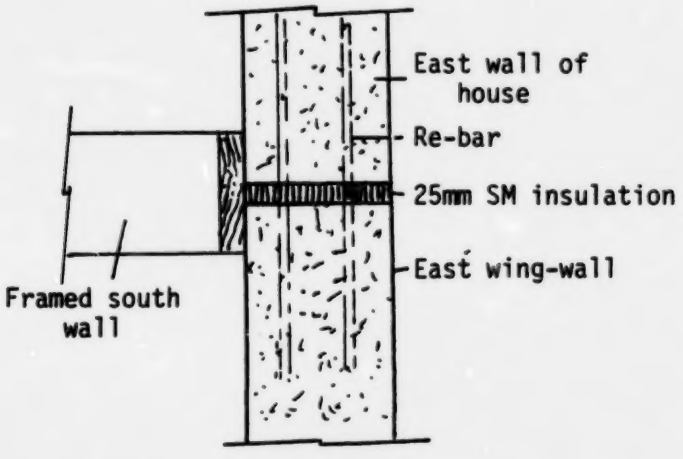


Figure 5. Assumed detail of thermal break at wing wall

4.5 Exterior insulation

The concrete shell was insulated on the exterior before back-filling. Sprayed urethane foam was used on the roof, rear wall and side walls.

Urethane foam was applied over the complete roof area, including the south overhang. Its thickness was tapered away from the centre to provide drainage runoff. When cured, the foam was about 4.5" (114 mm) thick at the centre of roof, tapering to 3.5" (89 mm) around the edges.

Foam was installed over the full height of the rear and side walls, right down to the footings. The cured thickness tapered from 3.5" (89 mm) at the top to 2.5" (63 mm) at the bottom.

When the urethane was cured, 3 to 4 coats of commercially available waterproofing were applied over the entire surface of the urethane.

The foundation wall along the south of the house was insulated with 1" (25 mm) Dow SM. No insulation was installed under the crawl space floor prior to concrete pouring. The intention was to leave this floor uninsulated, primarily to assist in house cooling in summer.

It should be noted that the installed cost of the urethane foam was $2 per square foot ($21.52 per m^2).

4.6 Service Entrances, Ventilation Ducts and Drainage

Before back-filling with earth the weeping tile system was placed around the footings and was provided with gravel drainage fill in accordance with code requirements. Underground electrical service and water lines from the farm well were installed.

Two uninsulated pvc pipes of diameter 6"(152 mm) and a single ABS pipe of diameter 4" (102 mm) were set into the ground, running for a distance of about 200 ft (61,000 mm) to the north of the house. These were connected to matching pipe sections that had been cast into the crawl space floor. For details of the pipe runs see figures 2 and 6.

The two pvc pipes were intended for use as ventilation inlets and outlets. The ABS pipe was intended for use as a combustion air supply inlet to the fireplace. These pipes would subsequently be covered by a thick layer of bermed earth, and were intended to give a slight heating effect in winter and a slight cooling effect in summer.

The pvc pipes were joined using O-ring seals and the ABS pipe was joined with ABS adhesive at the collars.

4.7 Berming

Earth was excavated on the west side of the farm entrance road to form a dugout (figure 2). About 3000 cubic yards (2290 m^3) were excavated, and about half of this was used in berming around the house. The remainder was used to form banks around the dugout.

The berming on the east and west sides of the house consisted of about 100 ft (30490 mm) of graded slope. The berming on the north consisted of about 200 ft (60,960 mm) of graded slope. Top soil was placed on the roof to a depth of 1.5 ft (457 mm) to allow future use of the roof as a combination passive solar collector and greenhouse (or an observation deck). Finally, the berming was seeded with rye grass for stabilization.

A water drainage ditch was provided on the west side of the house, running alongside the farm entrance road. Drainage is toward the south, where a culvert has been installed to direct the water under the road and into the new dugout.

4.8 Windows

All windows are located on the south wall, with the exception of the skylight in the roof above the family room. The windows were wood casement units with hermetically sealed double glazing, and were manufactured by R. L. Cushing Millworks in Moose Jaw. The windows have a single operator acting as a security sash lock. The frames have been supplied with extenders to fit the 2" x 10" (38 mm x 240 mm) framing on the south wall.

All window units were shrouded with 6 mil (0.15 mm) polyethylene before installation, in accordance with good air-vapour barrier construction. The exteriors were caulked and sealed against wind and water entry.

The skylight is a 1400 mm square unit which is yet to be incorporated in the roof above the family room. At present, the opening is fitted with a fixed-glazed living room window unit to keep out the weather.

The window package has been changed from that in the original design. This can be seen by comparing figures 1 and 4.

4.9 Doors

A single metal thermal door has been provided for entry through the south wall of the unheated garage. The patio doors are hermetically-sealed double-glazed units opening from the living room. Note the difference in designs in figures 1 and 4.

4.10 Interior insulation

North wall:
This has been fitted with a 2"x 4" (38 mm x 89 mm) wood frame with R12 (RSI 2.1) glass fibre batt insulation. No vapour barrier has been fitted at this stage.

West wall:
A 2" x 8" (38 mm x 190 mm) wood frame separates the heated living space from the unheated garage and cold room. The wall will accommodate two layers of batt, giving a total insulation level of R24 (RSI 4.2). The top and bottom plates had not been sealed to prevent air leakage between the garage and the living area. At the time of inspection the wall had not progressed to the stage of vapour barrier installation.

The electrical distribution service box was mounted on this wall, but facing into the unheated garage. The breakers will therefore be exposed to cold temperatures and possibly frost build-up.

East wall:
This wall is framed with 2" x 4" (38 mm x 89 mm) studs and has R12 (RSI 2.1) glass fibre batt insulation. The vapour barrier has not yet been installed.

South wall:
The wall is framed with 2" x 10" (38 mm x 240 mm) wood framing, set between the concrete support columns. The framing supports the door and window units. It is insulated with layers of glass fibre batt to R32 (RSI 5.6). The vapour barrier has not yet been fitted, though there are preparatory shrouds around the door and window units.

The exterior of the wood framing has been sheathed and cladding has been installed. This cladding has been carried across the exposed concrete columns to conceal them.

The main support beam, which runs across the top of the south wall, has been framed on the exterior but is not yet fully insulated.

4.11 Crawl space

This is insulated on the exterior only, with 1" (25 mm) Dow SM on the south and urethane on all other walls, as described earlier. There is no interior insulation, vapour barrier or finishing. The west side of the crawl space consists of a foundation wall adjoining the garage (see figure 4). This has no insulation at all to reduce heat losses from the crawl space into the garage and soil under the garage.

4.12 Ceilings

Currently, the ceilings consist of exposed concrete. It is proposed to insulate them as follows:

The bedroom ceilings will be strapped with 2" x 4" (38 mm x 89 mm) frame and insulated with R12 (RSI 2.1) glass fibre batt. The ceiling will be finished with vapour barrier and drywall.

In the family room, texture will be applied to the existing concrete surface.

In the living room, kitchen and dining room it is proposed to use a suspended ceiling using Sonatex ceiling tiles. No insulation will be added.

4.13 Heating systems

The house is currently heated by portable electrical baseboard heaters: two 1500-Watt units and one 1400-Watt unit. A total output of 4.4 kW. The owner has noted that, during the cold spell in December 1983, an interior temperature of 68°F (20°C) was maintained with only a 1500-Watt heater. The owner also noted that the garage temperature was maintained at 25°F (-4°C) with a 60-Watt light bulb.

Eventually, it is proposed to use a fireplace to supply all the space heating needs of the house. An Acorn #2000 fireplace has already been installed in the family room, against the west wall that backs onto the garage and the cold room. The fireplace is a second-hand unit* and is to be modified to interlock the flue damper with the fresh air intake. Fresh air will be supplied through the 4" (101 mm) ABS pipe mentioned earlier.

The fireplace unit was selected because the flue damper is located within the firebox rather than in the flue. This facilitates damper adjustment to provide a more controlled burn. The glass doors are a single unit, and although they are poorly sealed it will be possible to seal these better than most folding door designs. The main disadvantage of this fireplace design is that the fresh air feed can be diverted into the combustion chamber or out the front of the fireplace. There is an air passage connection between the combustion chamber and the living area, which by-passes the sealed glass door. This could lead to backdrafting effects, bringing combustion gases into the house air.

It is proposed to use a fan blower to push heated air through the fireplace jacket, in the reverse of the normal direction. This air will be diverted down into the crawl space, which will serve as a very large air-distribution plenum. Holes will be cut in the wood floor at various places around the house and will be fitted with registers. The design concept is based on the idea that the warm air will flow upwards from the crawl space, since it will have nowhere else to go. This design feature is one of the most problematic in the entire project, and will be discussed later.

4.14 Ventilation System

The owner proposes to draw exhaust air from the bathroom and kitchen, and vent these into the garage. The dryer will also be vented into the garage. The two 6"

* The fireplace is unused and is still under warranty.

pvc pipes, mentioned earlier, are terminated down in the crawl space, and their precise role in the ventilation system has not yet been determined by the owner.

The ventilation design is another major problem area and will be discussed later.

4.15 Garage and storage room

These are unheated areas. Fresh air intakes and exhaust stacks have been installed in the roof to allow fresh air movement through the stack effect. It is hoped that this will also maintain an adequate cool temperature in the cold room.

5.1 Code infringements

From an inspection of Residential Standards (3) the house has been found to have two code infringements:

- Section 7: Bedrooms are required to have "5 per cent of area served with at least one window having a minimum area of 0.55 m² and a minimum dimension of 600 mm." Two of the bedrooms in this house have no windows.

- Section 33: Where rooms have no windows for ventilation they must have some kind of mechanical ventilation system. This applies to the bathroom and two bedrooms.

No other code infringements have been identified. The concrete design and the earth-sheltering do not infringe the codes.

5.2 Urethane foam durability

The following quotations are taken from CGSB Standard 51-GP-46MP:

Chapter 2, page 10, section 2.13: "When urethane foam is being applied directly to the earth to be used as insulation, it is important that ground water be kept away from the urethane foam. It is recommended that a vapor barrier such as a polyethylene sheet should be placed over the ground prior to the application of the urethane foam."

Chapter 2, page 11, section 3.2: "Care should be taken whenever the relative humidity rises above 80%. High relative humidity can adversely affect physical properties of the urethane foam such as adhesion and can lead to a high water vapor or water content in the urethane foam resulting in lowered insulation value."

The thrust of these quotations is obvious: urethane is not resistant to water and must be protected from it. In this project the owner has protected the urethan with three-to-four layers of waterproofing. This

is an unconventional technique whose reliability does not appear to have been established in practice. There are two areas of concern:

- The durability of this method of waterproofing is uncertain. If it fails, the urethane will also fail - eventually.

- There is no information on the type of waterproofing used, and it is therefore difficult to say if it is chemically compatible with urethane.

The owner would be well advised to keep an eye on this, by conducting occasional inspections on the roof section.

5.3 Thermal bridging and heat loss paths

Looking at the way in which the house is actually built, and the way in which it is proposed to operate it, there are considerable areas and paths of heat loss. Most of these are shown schematically in figure 6. Referring to the alphabetic symbols in this figure:

A: There is a very strong conduction path through the support beam, along the overhang and downwards through the lower face of the overhang. The heat loss along this path will be enhanced by the reinforcing bars, which run in the direction of heat conduction. The insulated frame on the outside of the support beam does not restrict this heat loss. To solve this problem it would be advisable to insulate all ceiling sections adjoining the south wall, and to carry this insulation down the inside face of the support beam. If this is not done, there will be a high probability of severe cold spots along the top of the south wall and adjoining ceiling. Condensation problems could be serious.

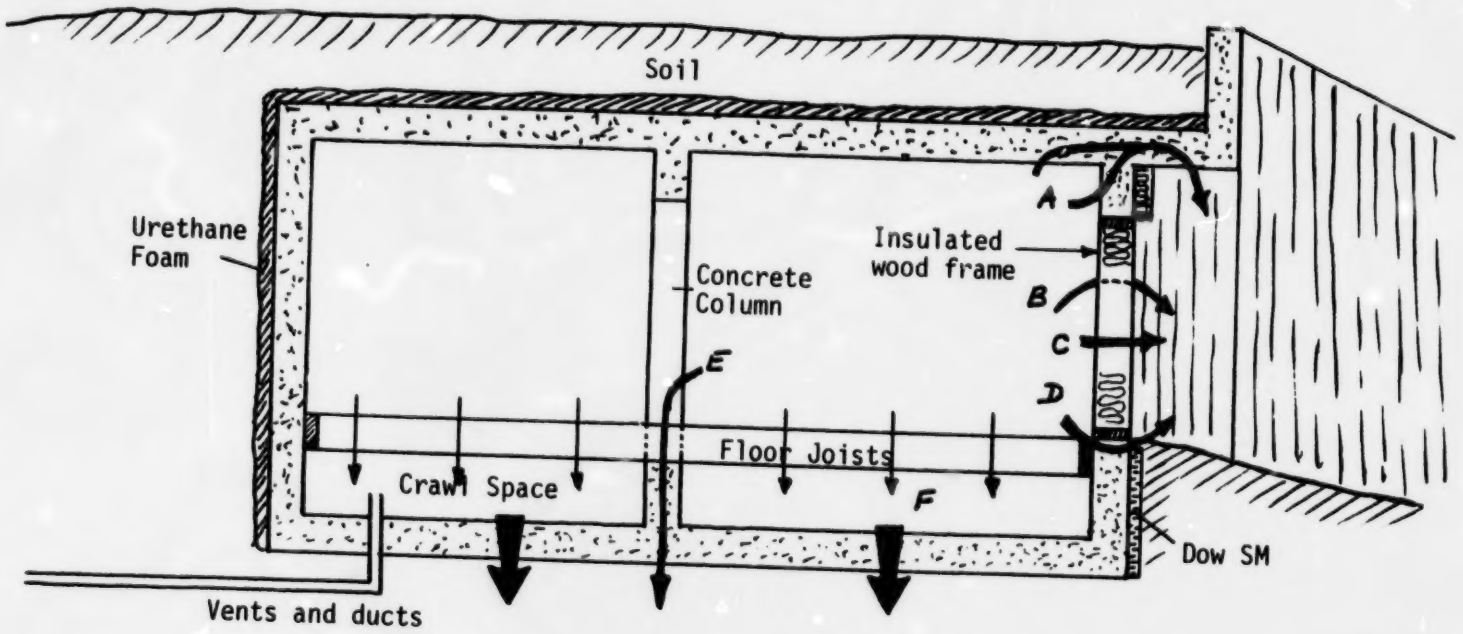


Figure 6. The main thermal bridging points and heat loss paths

B: The thermal break that has been installed between the side walls and the wing walls is not expected to be very effective. Referring to figure 5 it will be noted that the insulation is bridged by reinforcing bars, which probably conduct more heat than the entire cross section of the concrete. It is difficult to quantify this without knowing more about the reinforcing bar design and placement. In the authors' opinion the thermal break serves no useful purpose; the insulated frame against the east wall will provide the main thermal resistance, though it should be noted that the end stud of this frame will constitute a good thermal bridge connection to the concrete. This thermal bridging point could have been overcome by better framing design around this corner.

C: The existing south wall consists mainly of insulated wood frame, windows and doors. But at various points along this wall the concrete columns are buried inside the wall structure. These are serious thermal bridging points. They are covered with cladding on the outside, and will be covered with drywall or interior finish on the inside. There is no effective insulation on these columns. Severe cold spots can be expected to occur, and condensation may be excessive, particularly in the kitchen. Ideally, some kind of insulation should be installed on either the inside or outside face of the columns, but no obvious aesthetic solutions spring to mind.*

D: The Dow SM insulation stops slightly short of the top of the foundation wall. On the inside, there is an exposed concrete corner. A cold spot, with probable condensation problems, will occur along this bottom edge of the south wall. No obvious solutions spring to mind, except to install SM insulation along the outside of the wall and conceal this with planters.

E: This is a relatively weak heat loss path. Heat can flow down the concrete columns into the underlying soil. This process will be worsened by the reinforcing bars in the columns, which run vertically. It is probably not worth resorting to elaborate remedial measures around the columns.

* This problem has been created by the owner's departing from the original plan, in which the south wall was positioned inside the support beam and columns.

F: This is a different kind of heat loss situation. The joist floor is uninsulated and it is proposed to run the crawl space as a warm air plenum. This is highly undesirable for the following reasons:

- Since warm air from the fireplace jacket is being circulated through the crawl space, there will be an excessive heat loss down into the soil through the uninsulated concrete floor.

- This heat loss will create an extensive warm soil zone under the floor slab. Because of the high thermal mass of the soil, this warm zone will persist for many months - into summer and probably beyond. The effectiveness of the crawl space as a summer cooling device will be much impaired.

- The use of the crawl space as an air plenum requires that the space be hermetically sealed. If it is not sealed then there will be an even greater heat loss due to escaping warm air. At the bottom of the 8" frame wall on the east side of the garage there is an unsealed gap between the stud frame and the concrete. Air can escape through this. Moreover, there is already a crack in the concrete foundation wall on the east side of the garage, providing another escape path. Cracks in foundations are the rule rather than the exception, and it is not reasonable to treat a crawl space as a sealed system.

- The crawl space floor and walls are the strongest points of radon infiltration in this house. By circulating air continuously through the crawl space and bringing it back into the house, there will be a constant transportation of radon into the house air. Whether or not this is serious will depend on the properties of the surrounding soil and the constitution of the concrete. It would be unwise to proceed without checking this.

- Even though the crawl space is heated, the floor of the crawl space will be one of the coldest surfaces in the house. Condensation or frosting may occur.

Two remaining heat loss paths are indicated in figure 4:

G: The concrete roof provides a thermal bridge over the top of the dividing wall between the garage and the living area. There will be a continuous loss of heat into the unheated garage. The problem will be worst in the family room, where no insulation is planned for the ceiling. Cold spots will occur at the top of the dividing wall. It is difficult to predict their seriousness, but an insulated ceiling would eliminate the potential problem.

H: There will be a direct heat loss from the crawl space into the soil under the garage. This can be avoided by operating the crawl space as an unheated area, as recommended later.

5.4 Combustion air supply

The combustion air supply to the fireplace is brought in through a 200 ft length of 4" diameter pipe. A larger diameter - at least 6" - would have been preferable, and the pipe could have been made considerably shorter.

The reason for the long pipe was to use the soil temperatures to heat the incoming air in winter and cool it in summer. This is not an important consideration for combustion air, but in this case it was also proposed to use this air supply for ventilation purposes, by diverting it through a vent at the front of the fireplace. This is a poor design feature of this particular fireplace unit; it couples the combustion air to the ventilation air and can lead to combustion gases escaping into the house air. This method of ventilation should be abandoned. The combustion air supply should be only a combustion air supply.

5.5 Ventilation system

It is difficult to be specific about this, since the design has not yet been finalised. However, the practice of exhausting the dryer, the kitchen and the bathroom into the garage must be discouraged. There

are three undesirable factors involved in this practice:

- The discharge of highly humid air into the cold garage will cause excessive frosting and condensation in the garage.

- This frosting will be particularly hazardous in view of the fact that the electrical distribution panel has been mounted in the garage.

- It is potentially dangerous to have any vents running from the living area into an enclosed garage - no matter whether they are inlet vents or exhaust vents. No exhaust system can be regarded as totally foolproof, and there may be times when it is driven in the reverse direction - particularly in a fairly tight house. If reverse flow occurs, harmful car exhaust fumes can be drawn into the house.

5.6 Electrical distribution panel

It is not advisable to mount this panel outside the warm house envelope; the reliability of the breakers could be impaired if they are required to operate at low temperatures in possible conditions of frosting. If possible, the panel should be swung around and recessed into the 8" wall, facing into the house. Some insulation behind the panel would be advisable.

5.7 Vapour barrier

The vapour barrier has not yet been installed, but already it is obvious that the house design does not lend itself to a good, airtight vapour barrier installation. Problem areas have been identified on the insulated wall against the garage, the south wall, various parts of the ceiling and the floor.

5.8 Passive solar design

The passive solar performance of the house is impaired by the tree cover along the wind-break to the east. The house receives full solar gain only when the sun has cleared the trees, which usually occurs around 11.00 am in winter. If convenient, some thought should be given to selective removal of some of the trees.

Passive solar gains can create irregular temperature variations throughout the house, unless arrangements are made to distribute them through the house. This is particularly so in a house of this design, in which all windows except the skylight are located on the south wall. This design makes it almost mandatory to have a very effective air circulation system.

The interior layout shows that two bedrooms, the bathroom and the entry have no direct sunlight. Lighting bills will probably be slightly higher than normal in this house, and will lead to internal gains that will offset the need for direct space heating.

The following design changes are recommended to avoid moisture problems, combustion air supply problems and air quality problems.

6.1 Crawl Space

The crawl space must not be used as a warm air plenum, for the reasons given in section 5. Ideally, the crawl space should be operated as an unheated zone. The following treatments are recommended:

- Insulate the spaces between the floor joists above the crawl space. This insulation should be at least R20 (RSI 3.5), and should be held in place either with wire mesh or scrap lumber.

- The floor of the crawl space should be lined with polyethylene to serve as a moisture barrier.

- The crawl space should be fitted with vents to allow dissipation of accumulated moisture. The best way to do this seems to be to break through into the garage at the bottom of the wood frame wall on the east side of the garage. At least 1.5 ft^2 (0.14 m^2) vent area should be installed.

6.2 Insulation

It is recommended that all exposed concrete areas inside the house envelope be covered with insulation. The best way to do this is to strap the walls and insert glass fibre batt. This will minimise the heat losses through the various thermal bridges that have been identified. The following work is recommended:

- Cover all concrete on the ceilings and walls with 2" x 4" (38 mm x 89 mm) strapping and insulate with R12 (RSI 2.1) glass fibre batt. This work should be carried down over the interior face of the support beam on the south wall.

- Where the concrete support columns are buried in the south wall structure, some thought should be given to installing insulation on either the inside or outside faces.

- The soil outside the south wall should be excavated slightly, and the existing Dow SM insulation should be carried up the wall to a distance of at least 2" (51 mm) above the house floor. The homeowner should devise some way of protecting and concealing this insulation. Flashing should be installed above the insulation to prevent water from running down behind it.

- The concrete support columns running through the middle of the house will lose heat into the unheated crawl space. This heat loss can be reduced by insulating around the columns, either in the living area or in the crawl space.

6.3 Vapour barrier

The owner is advised to install a sealed air-vapour barrier according to the guidelines laid down in the book "Air-Vapour Barriers". Particular attention should be given to the sealing around penetrating pipes, concrete support beams and electrical cables. Note also that the vapour barrier must be carried across the house floor, over the unheated crawl space. It will be impossible to seal under the existing partition walls; the owner should do the best he can in the circumstances.

6.4 Venting exhaust air into the garage.

This must not be done.

6.5 Combustion air supply

The following changes are recommended. The owner is advised to check with the fireplace manufacturer regarding all changes to the fireplace, to ensure that an unsafe or non-warrantied change is not made.

- Where the three vent pipes emerge from the soil to the north of the house, the system should be modified so that there is a clearance of at least 6 ft (1830 mm) between pipes.

- One of these 6" (152 mm) vent pipes should be used as a combustion air supply inlet and should be connected to the fresh air facility on the fireplace.

- The fresh air supply duct should be provided with a controllable damper, designed so that it cannot cut off the airflow completely. A 2" (51 mm) diameter hole in the damper will suffice.

- The fireplace should be modified so that the fresh air supply to the combustion chamber cannot be directed into the house. This is an important safety factor. Good seals should be installed on the glass doors.
- If the fireplace displays obvious lack of draft with the above modifications, this is an indication that the combustion air duct is too long and is providing too much drag on the incoming air flow. If this happens the owner is advised to install a shorter duct with a larger diameter.

6.6 Ventilation system

This house must have a ventilation system to control odours, excess moisture and pollutants. The two remaining vent pipes under the soil should be used for this system. The 4" (102 mm) ABS pipe should be used for inlet and the 6" (152 mm) pvc pipe should be used for outlet.

The system should be arranged as shown in figure 7.

It should be noted that, with this design, the homeowner has inadvertently built a heat exchanger. The vent pipes run together for a distance of 200 ft. (61,000 mm) underground. The warm air flowing through the exhaust pipe will create a warm zone in the soil around the pipe, and some of this warmth will be passed to the incoming fresh air in the inlet pipe.

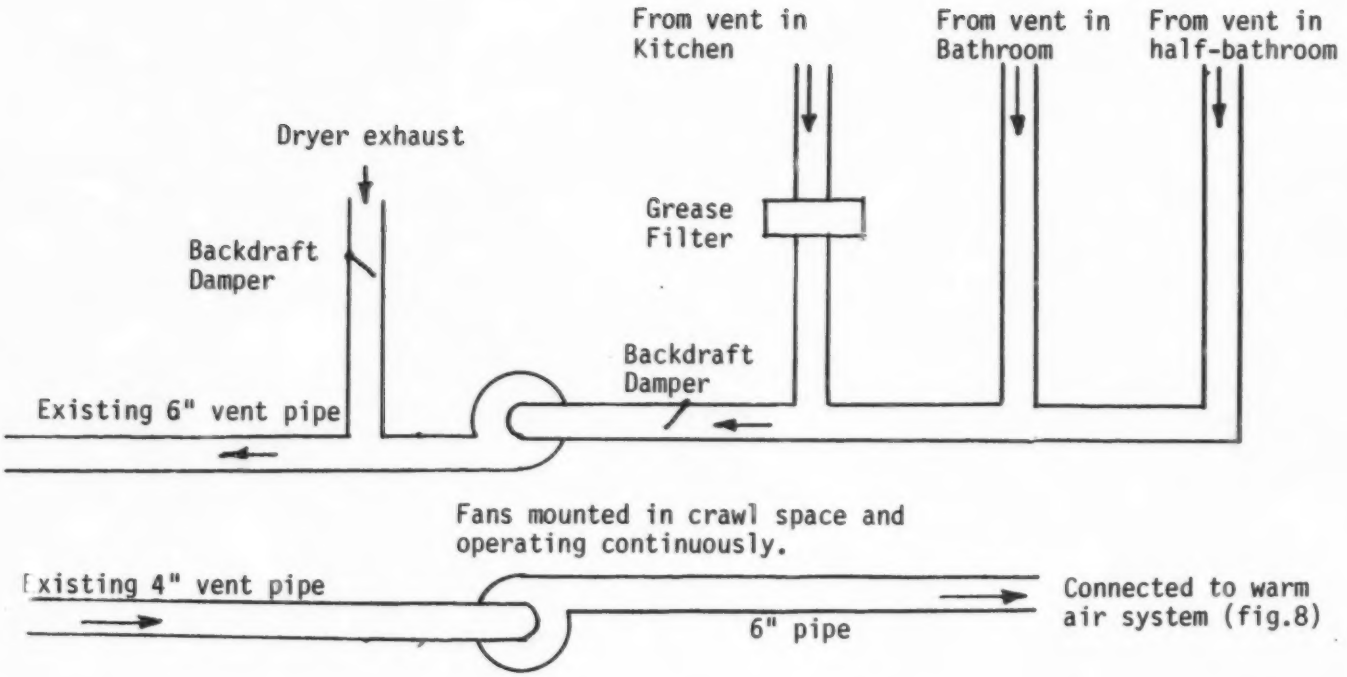
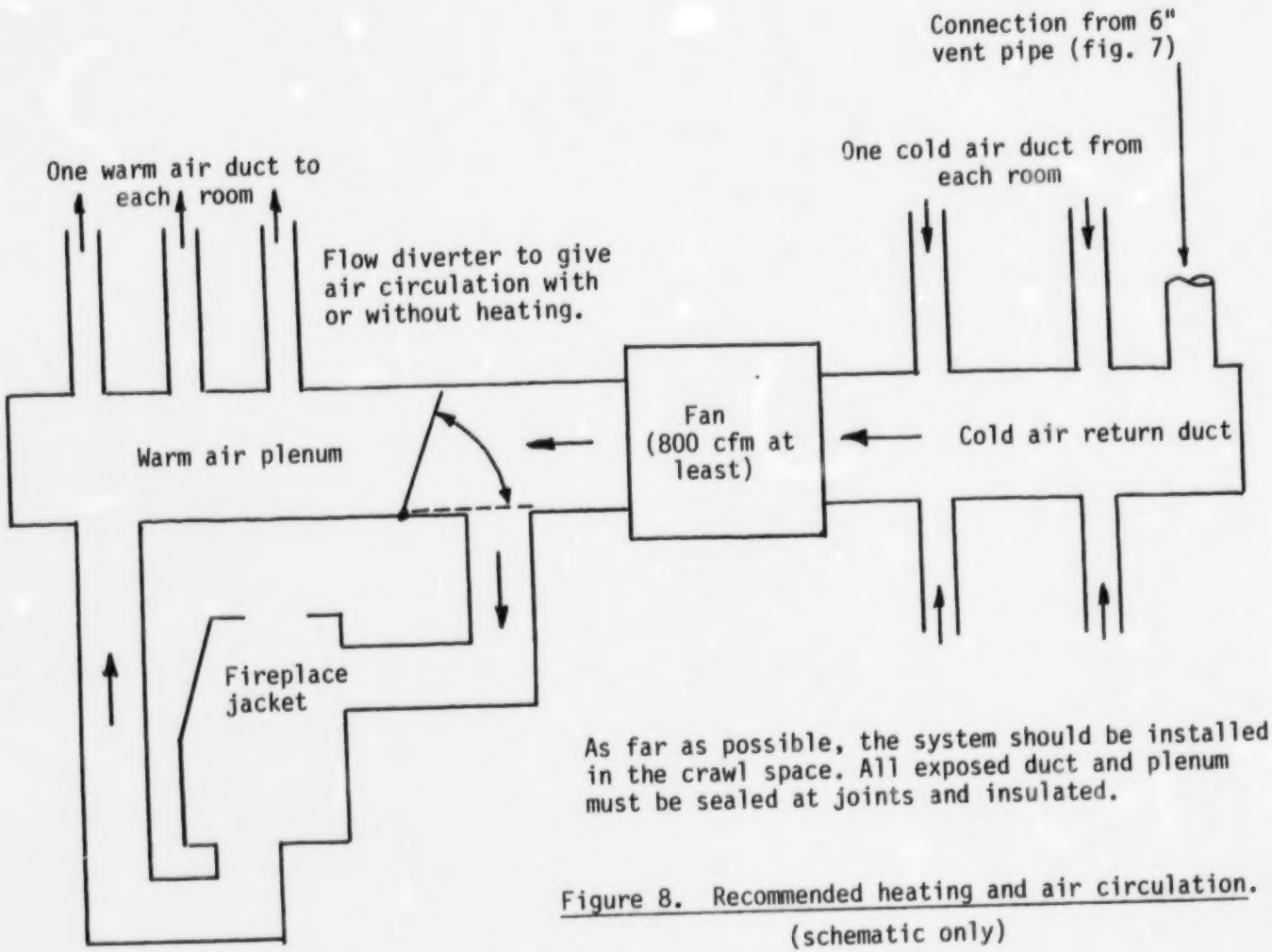


Figure 7. Proposed Ventilation System


Connection from 6" vent pipe (fig. 7)
One cold air duct from each room
One warm air duct to each room
Flow diverter to give air circulation with or without heating.
Fan (800 cfm at least)
Warm air plenum
Cold air return duct
Fireplace jacket

As far as possible, the system should be installed in the crawl space. All exposed duct and plenum must be sealed at joints and insulated.

Figure 8. Recommended heating and air circulation.
(schematic only)

Before installing the ventilation system the owner is advised to have the system properly designed by an engineering consultant, to ensure that it has a maximum flow capacity of at least 0.5 air changes per hour. The damper will allow the owner to reduce the flow rate and 'tune' it to the requirements of the house.

6.7 The heating and air distribution system

This house is well protected from severe weather and there will be an almost uniform temperature throughout the house interior. As a result, there will be very little movement of air. This will have two undesirable effects: firstly, it will give rise to zones of stale air and polluted air at various points inside the house. Secondly, the solar gains on the south wall will tend to cause local overheating since they cannot be distributed around the house.

Accordingly, it is strongly recommended that the owner install an air distribution system with a warm air outlet and a cold air return in every room. This can be coupled to the fireplace to deliver heat to the various rooms. A design is shown in figure 8.

The best place to install the ducting will be in the crawl space. All ducting in this space should be sealed and insulated.

The owner is advised to have this system designed by an engineering consultant.

6.8 Electrical

The owner is advised to relocate the electrical panel inside the heated area of the house.

The electrical work should be installed so as to maintain the integrity of the vapour barrier. The owner is advised to consult the publication "Air-Vapour Barriers" (4) on this.

6.9 Passive solar

Some consideration should be given to selective removal of some of the trees in the wind-break, to give better access to solar radiation in the morning.

6.10 Urethane insulation

The author has doubts that this insulation will last. The owner is advised to inspect the insulation every two years or so for any evidence of degradation.

The earth-sheltered home at Keeler, Saskatchewan is not yet complete. Some insulation work has been done, but there is no vapour barrier installation or finishing. The heating and ventilation systems have not yet been installed.

Having inspected the design and construction, it is now clear that this type of earth-sheltered home should conform to the following design requirements:

> The concrete shell should be regarded solely as an earth-containment shell, and should be designed to withstand the soil loadings over an indefinitely long period.
>
> The main house envelope should be constructed inside the shell, and should consist of a continuous insulated envelope with a continuous air-vapour barrier.
>
> Ventilation and combustion air supply systems should conform to the best practices now being developed for energy-efficient housing.

If these design features are not followed, then the shell will consist of a mixture of wood-frame sections and exposed concrete, This has been shown to lead to excessive heat loss due to unavoidable problems with thermal bridging and discontinuity of the vapour barrier. Eventually, the thermal bridging may lead to localised condensation damage.

A number of problem areas have been identified in the house, which might lead ultimately to moisture damage, poor air quality and combustion air supply problems. Recommendations for major changes have been made to the owner, to make the various details conform to good good, safe building practice. The problem areas and the recommended solutions have been reviewed in detail in this report.

The earth-sheltered concept is the outstanding feature of this house, but the ultimate performance of the house will be determined by the other features of the construction and the owner's willingness to incorporate the recommended changes. In this respect, the most important factors relate to the insulation of

existing thermal bridging paths, the elimination of the crawl space as a warm air plenum, and the installation of air management systems along the lines recommended.

Since the house is not yet completed, and since its final design details are still not certain, it has been impossible to quantify its energy-efficient performance. There are indications that the house is already highly energy-efficient, even in its present stage of construction. However, this level will probably decrease once the house is fully operating with ventilation air and combustion air supply. The recommended changes will help the owner to maintain a high level of thermal efficiency, and will ensure that the house is safe for living in.

Full cost records have not been kept, and the owner has obtained many services and materials at atypically low costs. Accordingly, it has not been possible to conduct even a simple economic analysis on this house, and it is doubtful that such an analysis would have been typical in any case.

1. Rodale's New Shelter. January 1982. Contains several articles on earth-sheltered houses.

2. Eyre, D. and Hesterman, L. The Thermal Performance of House Utility Connections in Northern Saskatchewan. SRC Publication No. E-825-3-B1-81

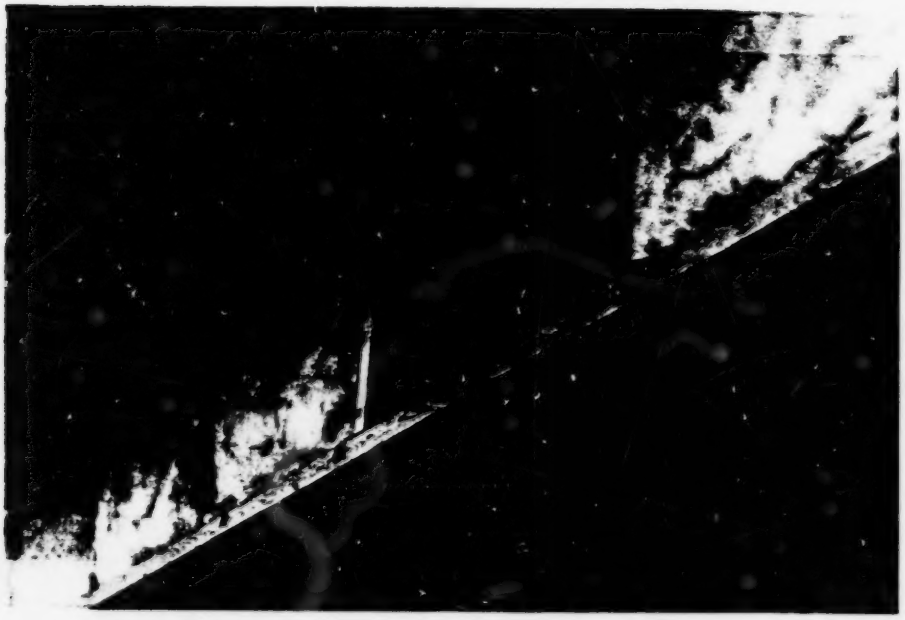
3. Residential Standards 1980 Published and issued by National Research Council, Ottawa.

4. Eyre, D. and Jennings, D. Air-Vapour Barriers SRC Publication, distributed by the BETT Program of Energy, Mines and Resources, Ottawa.

APPENDIX I

Photographic views.

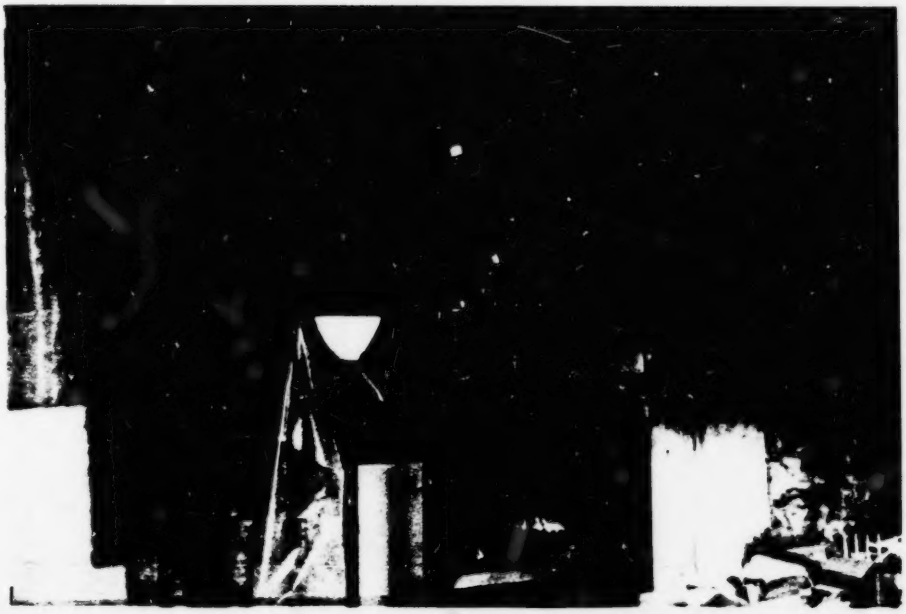
South face of the house



Insulation over main support beam on south wall

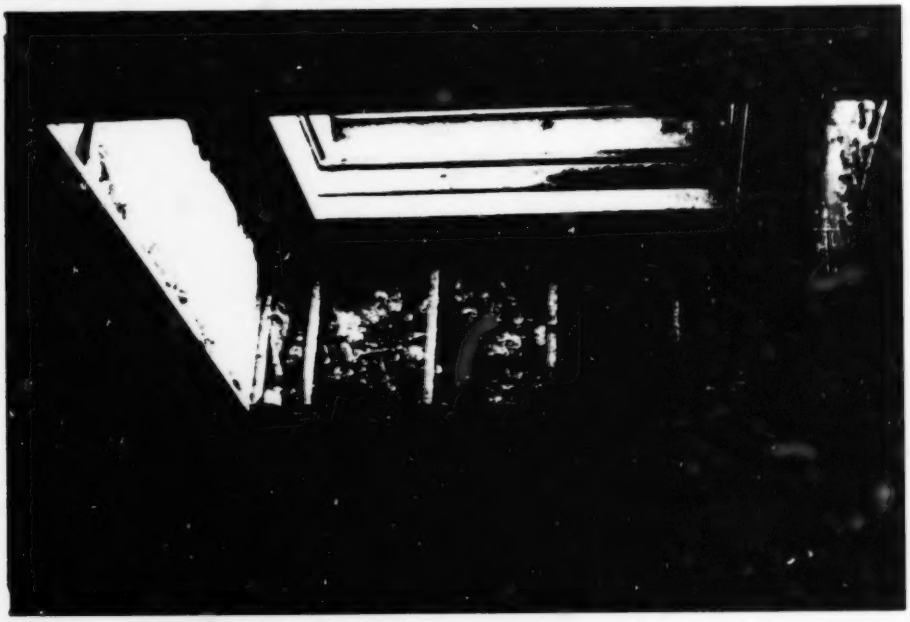
Interior view, March 23. Note lack of insulation at junction of ceiling and support beam

Window detail, showing preparatory vapour barrier

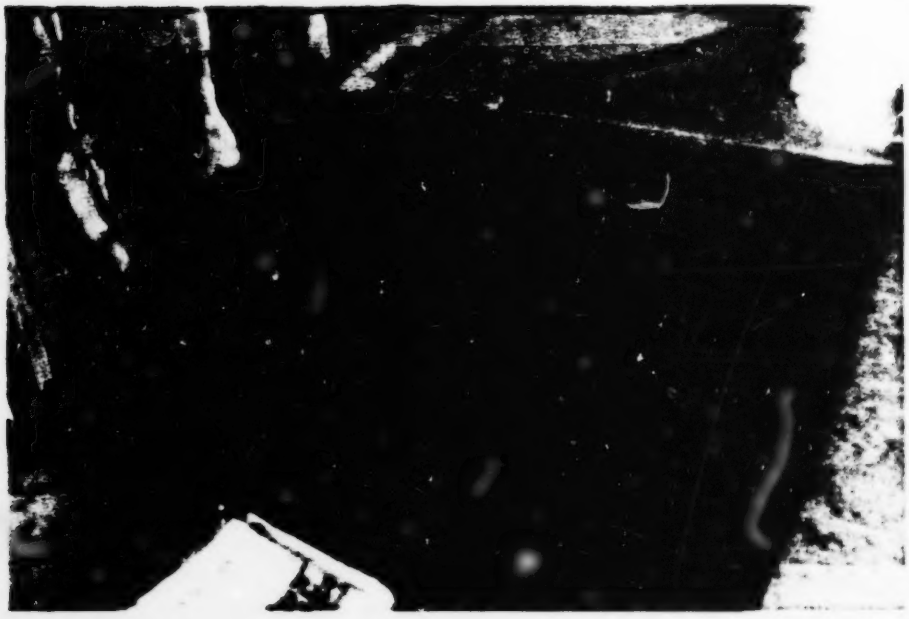


Fireplace against insulated west wall adjoining garage.

Exterior door connecting to garage. Note that the electrical distribution panel faces into the unheated garage.



Skylight



Access to crawl space.